ORIGINAL ARTICLE

# Living organisms and sedimentary remains from high mountain lakes in the Alps

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**ABSTRACT**

We publish a data set of environmental and biological data collected in 2000 during the ice-free period in high mountain lakes mainly located above the local timberline in the Alps, in Italy, Switzerland and Austria. Environmental data include coordinates, geographical attributes and detailed information on vegetation, bedrock and land use in lake catchments. Chemical analyses of a sample for each lake collected at the lake surface in summer 2000 are also reported. Biological data include phytoplankton, zooplankton, macroinvertebrates, benthic diatoms. Diatoms, cladoceran and chironomids remains and algal and bacterial pigments were also analysed in lake sediments.

## INTRODUCTION

Limnology of Alpine lakes dates back to the end of the 19th century, mainly focusing on the presence and composition of benthic and plankton fauna, with a predominantly taxonomic approach in the description of biological diversity (Pero, 1893; Zschokke, 1894; Bourcart, 1906; Pesta, 1912; De Marchi, 1913). Later on, Alpine lakes were used as experimental fields to test general ecological theories (Baldi, 1937; Bossone and Tonolli, 1954), analysing for example life history parameter estimates (Ravera and Tonolli, 1956), seasonal developments of plankton (Ferrari, 1967), and productivity measurements (de Bernardi *et al.,* 1983).

Starting from the 1950's, a number of surveys of the chemical and biological features of Alpine lakes was carried out. In a pioneering exercise of citizen science, Tonolli and Tonolli (1951) asked alpinists to send lake plankton samples collected with a common protocol and produced an account of the relationships between the biological communities and the main environmental parameters of 170 lakes. Thirty years later, a similar exercise was carried out, including also the examination of net phytoplankton and chemical analysis of lake water of about 300 lakes, 46 of them included in the previous survey (Giussani *et al.,* 1986).

Some further surveys were carried out in the 1990s, collecting and analysing surface sediment samples in order to establish species-environment relationships to be used for inferring past lake condition from the biological remains of specific groups such as diatoms, cladocera, and chironomids found in sediment cores (Marchetto and Schmidt, 1992; Lotter *et al.* 1997, 1998). In Summer 2000, within the EU-funded programme EMERGE ("European Mountain lake Ecosystems: Regionalisation, diaGnostic & socio-economic Evaluation") aimed at assessing the status of remote mountain lake ecosystems throughout Europe, chemical, morphological and biological information was collected from a large number of high mountain lakes (72 from the Alps), including for the first time both living and sub-fossil components, using common standard protocols, mainly based on the experience of a previous EU-funded programme ("MOLAR, Measuring and modelling the dynamic response of remote mountain lake ecosystems to environmental change: a programme of MOuntain LAke Research"). The collected data refer to living organism and to remains found in surface sediment (assumed to represent the "present" condi-

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tion) and at ca. 10-cm depth, assumed to refer to pre-industrial condition, to allow the identification of changes due to the long-range transport of atmospheric pollutants. The absence in the latter samples of spherical carbonaceous particles, typical of industrial combustion, was used to verify their pre-industrial deposition (Rose *et al.*, 1999).

This large amount of environmental data was used for ecological studies (Marchetto *et al.*, 2009) and can still be useful for long-term comparative analyses, or for developing or testing ecological methods and theories. The aim of this data paper is to gather the massive amount of data collected in 2000 within the EU-funded programme EMERGE for 72 high mountain lakes from the Alps in a formal dataset in order to make it available for its further use by other studies.

Other studies concerning a large number of high mountain lakes were published, treating sedimentary remains (Bigler *et al.*, 2008; Kuefner *et al.*, 2020), living macroinvertebrates (Boggero *et al.*, 2008; Fureder *et al.*, 2006; Boggero and Lencioni, 2006), plankton (Maiolini *et al.*, 2006; Obertegger *et al.*, 2010; Horvath *et al.*, 2016; Tolotti *et al.*, 2018), and benthic diatoms (Feret *et al.*, 2018), as well as literature reviews (Jersabek *et al.*, 2001; Ruffo and Stoch, 2005; Boggero, 2018; Stoch *et al.*, 2019).

## METHODS

The 72 study lakes, mainly located above the timberline, were selected to avoid anthropogenic disturbance in the catchment, for instance by sewage discharge. Their location is shown in Fig. 1. The major direct human impacts affecting these lakes are fish introduction, tourism and alpine pastures within the catchment. In addition, the lakes are subject to the deposition of airborne pollutants, in particular acidifying compounds (sulphur and nitrogen) (The MOLAR Water Chemistry Group, 1999), persistent organic pollutants (POPs) (Grimalt *et al.*, 2001) and heavy metals (Hofer *et al.*, 2001).

Geo-referenced coordinates, geographical attributes and detailed information on vegetation, bedrock and land use in lake catchments were collated for each lake. Water samples were collected at the lake surface, on the vertical of the deepest point, and analysed for pH, conductivity, alkalinity, ammonium, total nitrogen, reactive and total phosphorus, reactive silica, major cations (calcium, magnesium, sodium, potassium) and anions (sulphate, nitrate, chloride), and dissolved organic carbon (DOC). As part of the analytical quality control within each laboratory, a check of the ionic balance was performed and a comparison between measured and calculated conductivity undertaken for all analyses. In lakes with maximum depth 5 m or less, samples for bacteria and chlorophyll were collected with the top end of the sampler 0.5 m below lake surface. In the other lakes, samples were collected at 1.5 times the Secchi disk reading, or 0.5 m or less above the bottom if the Secchi disk reading was 1 m or less above the bottom. Samples for chlorophyll were filtered through Whatman GF/F filters, kept in cool dark and frozen as soon as possible. Chlorophyll a was measured after gentle

**Fig. 1.** Location of the sampled lakes.

filtration and concentration on Whatman GF/F glass fibre filters, extracted in acetone and determined spectrophotometrically or fluorometrically (Wathne and Hansen, 1997). Bacteria were determined from formaldehyde preserved samples (final concentration 2% w/v) using 0.2 µm pore size black polycarbonate filters (Poretics or Nuclepore), DAPI stain and epifluorescence microscopy (Porter and Feig, 1980). Bacterial cells were counted and then sized by image analysis (widths and lengths measured) and their volumes calculated as cylinders with 2 hemispheres (Psenner, 1993).

Lake sampling took place during late summer or early fall according to a common sampling protocol (Fjellheim *et al.*, 2000). Samples were taken from the littoral and sieved through a net with 250 µm mesh size, and preserved in 70% ethanol. In each lake, samples from the range of available habitats were amalgamated to one sample prior to analysis. Benthic animals were identified to species using a binocular and/or a microscope. Chironomid larvae were mounted in Hoyer's solution on microscopic slides and identified to the lowest taxonomic level possible. Most animal groups were identified to the species level. In cases of differences in taxonomic precision between the participating institutions, the highest taxonomic level was chosen to facilitate comparison between regions (Schnell *et al.*, 1999).

Phytoplankton samples were collected through Ruttner or Patalas bottles, 1 m below Secchi depth or 1 m above the bottom in those lakes where the Secchi disk was still visible on the bottom. Samples were then fixed in Lugol's solution. Counting, measuring and taxonomic determination were performed in sedimentation chambers under the inverted microscope following Utermöhl (1958). Zooplankton samples were taken by several vertical hauls in proximity to the deepest point of the lake, using a 200 µm plankton net for quantitative samples. Samples were preserved in 4% formaldehyde or in ethanol. Taxonomy mainly followed Smirnov (1974, 1996), Kiefer (1978), Margaritora (1985), Einsle (1993), and Flößner (2000) for planktonic crustaceans.

Epilithic diatom samples were collected by brushing 10-12 small stones from 3 points around the lake, less than 1-m deep. They were then fixed in Lugol's iodine solution and mounted in Naphrax. Diatoms were analysed using a microscope at 1000x magnification and identified to species level. Diatom taxonomy mainly followed Krammer and Lange-Bertalot (1986, 1988, 1991a, 1991b). Sediment samples for cladocerans, chironomids, diatoms and pigment analyses were collected using a gravity corer and sliced in the field. The top 0.5 cm of each core was used as the surface sediment sample to represent the current condition, while a second sample at ca. 10-15 cm of depth was used as the "pre-industrial" sample. For diatom analysis, about 10 mg of sediment was cleaned using standard techniques (Renberg, 1990) and counted under oil immersion at a magnification of 1000x. Diatom taxonomy mainly followed Krammer and Lange-Bertalot (1986, 1988, 1991a, 1991b). The samples for pigment analysis were preserved deep-frozen until the analysis. A sub-sample of ca 2 g wet sediment was weighed and extracted overnight with ca. 10 mL of an acetone/water mixture (90:10). The extract was then centrifuged at 3000 rpm for 10 min in a glass centrifuge tube and used for total pigment and for specific chlorophyll and carotenoid determinations through HPLC chromatography following Lami *et al.* (1994).

Cladoceran sub-fossil remains were counted in ca. 3 g of wet sediment. The samples were deflocculated in warm 10% KOH for 2 hours and then digested in 10% HCl (Frey, 1986) or freeze-dried sediment was heated to boiling point in 50 mL of 10% KOH for about 30 min, being continuously mixed with a magnetic stirrer (Frey, 1958 modified according to Pražáková and Fott, 1994). Cool samples were filtered through a phosphorus-bronze sieve (mesh-size 40 $\mu$m), washed with water, and transferred into a mixture of glycerine, 70% ethanol and chlorazol black (Schmid *et al.*, 1998). Chydorid remains were determined according to Smirnov (1974, 1996), Margaritora (1985), Frey (1986) and Floßner (2000). At least 200 remains were counted and identified following Frey (1958, 1960) at magnifications between 100 and 200x. Several different cladoceran remains were identified, namely postabdominal claws, ephippia, head shields, postabdomens, valves, and their number were combined in order to obtain a minimum number of animals per sample following Frey (1986).

Chironomid analyses were performed following Hofmann (1986) and Warwick (1980). From each sample, 5-15 g wet sediment was deflocculated with hot KOH (10%) for 45 minutes. The remains of each section (previously sieved through 280, 200 and 150 µm mesh size) were picked out and mounted with Canada balsam for microscopic identification.

Alternatively, chironomid head capsules were obtained by sieving the sediment through a 90 $\mu$m screen after deflocculating with hot 10% KOH for 15 min. The head capsules were hand sorted from a Bolgorov tray with forceps under the 40x magnification of a stereoscopic microscope. The capsules were then mounted in Euparal medium after dehydration with absolute ethanol. Taxa were determined mainly following Schmid (1993) and Rieradevall and Brooks (2001). Only some of the chironomids were identified to the species level; others were identified only to genus or, in a few cases, tribe or subfamily.

For all biological analysis, taxonomic consistence was obtained through discussion among taxonomists in specific project workshops.

## RESULTS

### Data set description

This data set includes biotic and abiotic information from 72 lakes in the Alps, ordered in the following 10 sheets, gathered together into an Excel file:

i. Location and morphometry (of the lakes), described in Tab. 1;
ii. Water chemistry, containing five columns: Lake ID (Tab. 1), compound name, compound code, value, unit.
iii. Phytoplankton counts, containing five columns: Lake ID (Tab. 1), taxon code, taxon name, division, and percent abundance;
iv. Zooplankton counts, containing seven columns: Lake ID (Tab. 1), taxon code, species name, authorship, AphiaID (Worms Editorial Board, 2021), group, percent abundance;
v. Epilithic diatoms, containing four columns: Lake ID

**Tab. 1.** Content of the sheet "Location and morphometric characteristics of the lakes".

| Column name | Content | Unit | Data type |
|---|---|---|---|
| LakeID | Lake identifier | | Text |
| LakeName | Lake name | | Text |
| Lat | Latitude N WGS84 | Degree | Floating |
| Lon | Longitude E WGS84 | Degree | Floating |
| Alt | Lake altitude | m above sea level | Integer |
| C_area | Catchment area | Hectares | Floating |
| GeolMet | Metamorphic rocks in catchment | Percent | Floating |
| GeolPlut | Plutonic rocks in catchment | Percent | Floating |
| GeolVolc | Volcanic rocks in catchment | Percent | Floating |
| GeolDet | Detrital rocks in catchment | Percent | Floating |
| GeolCarb | Carbonate rocks in catchment | Percent | Floating |
| Glaciers | Catchment glaciated | Percent | Floating |
| GeolGlac | Glacial deposits rocks in catchment | Percent | Floating |
| Bare | Bare ground in catchment | Percent | Floating |
| Moorland | Moorland in catchment | Percent | Floating |
| Peat | Peat in catchment | Percent | Floating |
| Meadow | Meadow in catchment | Percent | Floating |
| Shrubs | Shrubs in catchment | Percent | Floating |
| Con_wood | Coniferous woodland in catchment | Percent | Floating |
| Dec_wood | Deciduous woodland in catchment | Percent | Floating |
| Rural | Rural area in catchment | Percent | Floating |
| Max_Alt | Maximum catchment altitude | m above sea level | Integer |
| Chain | Position of lake in chain | From top to bottom | Integer |
| L_area | Lake area | Hectares | Integer |
| Depth | Maximum Lake Depth | m | Floating |
| Lit_Rock | Littoral zone that is rocky | Percent | Integer |
| Lit_sand | Littoral zone that is sandy | Percent | Integer |
| Lit_Org | Littoral zone that is organic | Percent | Integer |
| Inlet | Presence of an inflow stream | true=1 | Logical |
| Outlet | Presence of a lake outflow stream | true=1 | Logical |
| Seepage | Whether the lake is a seepage lake | true=1 | Logical |
| Resid | Calculated residence time | Years | Floating |
| Secchi | Secchi Disc Depth | m (-9999 = bottom) | Floating |
| Bacteria | Total bacteria biomass | µg C $L^{-1}$ | Floating |
| ChlConc | Concentration of chl a | µg $L^{-1}$ | Floating |
| Fish | Fish Presence | Yes/no/unknown | Text |
| IceCover | Ice cover length | Days | Integer |

(Tab. 1), taxon code, taxon name, and percent abundance;
vi. Littoral macroinvertebrates, containing five columns: Lake ID (Tab. 1), taxon code, Taxon name, order and relative abundance;
vii. Sedimentary cladoceran (remains), containing seven columns: Lake ID (see Tab. 1), depth into the sediment (in cm), taxon code, taxon name, AphiaID (Worms Editorial Board, 2021), remain, remains per gram of dry sediment;
viii. Sedimentary diatoms, containing five columns: Lake ID (Tab. 1), depth into the sediment (in cm), taxon code, taxon name, and percent abundance;
ix. Sedimentary chironomids, containing five columns: Lake ID (Tab. 1), depth into the sediment (in cm), taxon code, taxon name, and percent abundance;
x. Sedimentary (algal and bacterial) pigments containing six columns: Lake ID (Tab. 1), depth into the sediment (in cm), compound name, compound code, value, unit.

Taxon names consist of the original species name, as given in 2000, and they were not updated, but in each sheet, diatom synonyms were merged, when present

In some cases, in particular for living phytoplankton and some macroinvertebrates, identification at the species level was not possible and "sp.", "gr.", "indet." were reported.

Not all organisms were collected in every lake. The number of lakes, taxa and relative abundance values included in each file are reported in Tab. 2.

### *Data set information*

Object name: Living organisms and sedimentary remains from high mountain lakes in the Alps.
Data set citation: EMERGE Alpine lakes
Format name: xlsx, Excel file
Distribution (permanent link): https://zenodo.org/record/5205468
Date of creation: 26 January 2021
Date of last revision: 16 August 2021
Date of publication: 16 August 2021
Update policy: not updated
Language: English
License of use: the access and the use are free. Data set authors would appreciate users providing a link to the original data set, and a citation to the present paper, or to be included as co-author in a new paper.
Metadata language: English
Metadata managers: Aldo Marchetto (aldo.marchetto@cnr.it)
Project title: Living organisms and sedimentary remains from high mountain lakes in the Alps.
Database manager: Aldo Marchetto
Temporal coverage: Summer 2000
Funding grants: European Union, EMERGE Project (contract No. EVK1-CT-1999-032)
Study area: mountain lakes in the Alps with surface standing waters showing areas greater than 0.1 ha (0.001 $km^2$), maximum depth greater than 1 m, at mean water level, placed in proximity of or above the tree line. The latter is a non-linear wavy line between the subalpine and the alpine areas, drawn based on tree-growth limiting factors (Körner, 1998).
Bounding box:
Min longitude: 7.40 - max longitude: 12.77
Min latitude: 45.94 - max latitude: 47.43
Min altitude: 1592 - max altitude: 2796 m asl
Sampling design: One sampling activity during the ice-free period 2000
Habitat type: Natural lakes (*i.e.*, lakes without anthropogenic infrastructures)
Biogeographical region: Alpine (EEA, 2002)
Countries: Austria, Italy and Switzerland
Quality control for geographic data: coordinates were collected by GPS during sampling and verified on topographic maps.



**Tab. 2.** Number of data.

| Data sheet | N. of lakes | N. of taxa or variables | N. of data |
|---|---|---|---|
| 1. Location and morphometry | 72 | 35 | 2496 |
| 2. Water chemistry | 71 | 15 | 971 |
| 3. Phytoplankton counts | 46 | 284 | 843 |
| 4. Zooplankton counts | 52 | 28 | 235 |
| 5. Epilithic diatoms | 71 | 68 | 1256 |
| 6. Littoral macroinvertebrates | 58 | 45 | 508 |
| 7. Sedimentary cladocerans | 68 | 37 | 1064 |
| 8. Sedimentary diatoms | 70 | 349 | 2983 |
| 9. Sedimentary chironomids | 20 | 48 | 248 |
| 10. Sedimentary pigments | 70 | 64 | 7121 |

Taxonomic coverage: phytoplankton, zooplankton, macroinvertebrates, diatoms.

Taxon specialist: Consistency of the taxonomy in the data set was granted by taxonomic workshops during the EMERGE and MOLAR projects.

Quality control for taxonomic data: before publication of the data set, algal taxon spelling and authorship were verified using Algaebase: Listing of World's Algae (Guiry and Guiry, 2021). The same control was performed on macroinvertebrates and zooplankton using Fauna Europea (De Jong *et al.,* 2014) and WoRMS, the World Register of Marine Species (WoRMS Editorial Board, 2021).

## CONCLUSIONS

The present dataset covers a wide variety of information from abiotic (morphological, geographic, physical, chemical) to biotic (plankton, benthos, diatoms, sedimentary remains) unique in its kind and format. Following the tradition of leaving data collected in mountain lakes to free access started by Tonolli and Tonolli (1951) and Giussani *et al.* (1986), we agreed to publish the EMERGE Alpine data set in the present form in order to share knowledge acquired on high altitude lakes for a better understanding of the functioning of these ecosystems under threat due to global climate change and other anthropogenic impacts.

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